TITLE: Acquiring Distance Knowledge in Virtual Environments

Acquiring Distance Knowledge in Virtual Environments

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Abstract
Experimental results on the perception and cognition of distances in virtual environments are reported. These results show differences in the accuracy of distance perception depending on whether they are presented in desktop- or HMD-VR. In addition, they show that distance cognition in virtual environments is based on online-judgements (perception based) or on inferential judgements (memory based) depending on the subject's goal when navigating through the environment. Without an explicit goal to learn distances (incidental learning condition) the estimated length of routes in a virtual environment is inferred by the number of features (feature-accumulation-hypothesis) experienced on the respective route, just like in natural environments.

1. Introduction

A spatial environment can be explored directly or by means of a map. A number of studies dealing with the acquisition and representation of and the access to spatial information have documented differences in spatial learning associated with different modes of experience. Direct and map experience lead to a different understanding of the environment. Navigating through an environment enables subjects to estimate route distances and route orientations (route knowledge), whereas Euclidean distances and locations of landmarks (survey knowledge) are easier to estimate if the environment is presented using a map (Thorndyke & Hayes-Roth, 1982; Giraudo & Pailhou, 1994; Taylor & Tversky, 1996).

Spatial cognition research is becoming increasingly interested in the use of virtual environments as experimental settings: virtual reality technology provides both an economical and flexible design of realistic environments as well as a reliable registration of the subjects interactions with the environment.

The results of spatial cognition research are of practical interest when virtual environments are used as visualisation or training tools. Thus the question arises, whether there are differences in processing spatial knowledge (landmark-, route- or survey-knowledge) in natural and virtual environments (Wilson, 1997; Witmer, Bailey, Knerr & Parsons, 1996; Ruddle, Payne & Jones, 1997; Rossano, West, Robertson, Wayne & Chase, 1999).

The paper refers to the acquisition of distance-knowledge in virtual environments, and to the perception and cognition of distances.

In chapter 2 an experiment designed to compare desk-top and HMD-VR with respect to supporting distance perception is presented.

In chapter 3 a series of experiments on distance *cognition* in virtual environments are reported.

Chapter 4 summarises and discusses the results presented.

2. Distance Perception and Perceived Depth in Virtual Reality

There are different kinds of psychological spaces. A vista space means a space up to 30 m, explored by looking ahead without locomotion. This kind of psychological space can be contrasted with the environmental space (the entire space is not visible from the starting position, it can be explored only by locomotion), and the geographical space (the space is so large, that it can be explored only by means of a map).

When designing vista spaces in virtual reality factors determining human space-perception have to be considered. There are nine different sources of information the human visual system uses as depth cues: occlusion, height in the visual field, relative size, relative density, aerial perspective, binocular disparities, accommodation, convergence and motion perspective (see Cutting, 1997). It is of interest, however, whether the perceiver's kind of interaction with the virtual environment (e.g. whether the view's orientation changes depending on the user's head movements, or not) may also affect their spatial sensitivity and thus their perception of distances in the space.

The hypothesis that distance perception in a virtual vista-space is more accurate in HMD-VR than in desktop VR is tested in a bisection-experiment.

A total of 18 subjects (7 male and 11 female) participated in the experiment. Their average age was 26 years, ranging from 20 to 36 years. The environment used in this experiment was created and presented using Superscape VRT 5.50 software, running on a 500 MHz Pentium III PC equipped with 196 MB RAM and a 32 MB Matrox G400 graphic accelerator card.

The environment showed a small forest through which a path led. The whole scene consisted of 8000 facets, and the maximum frame rate was limited to 20 frames per second to avoid lag differences. The environment was rendered in 640 to 480 pixel resolution.

Half of the group of subjects experienced the virtual environment by means of a head-tracked HMD

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(Virtuality Visette Pro combined with a Polhemus InsideTrak), the other half viewed the environment as a video projection (JVC DLA 10 SXGA). It was made sure that the FOV in both VR conditions was identical. In both conditions the subjects remained in a standing position.
The subjects were instructed to bisect a route presented to them in the virtual environment by moving a marker to the mid of the route. Figure 1 shows the virtual environment.

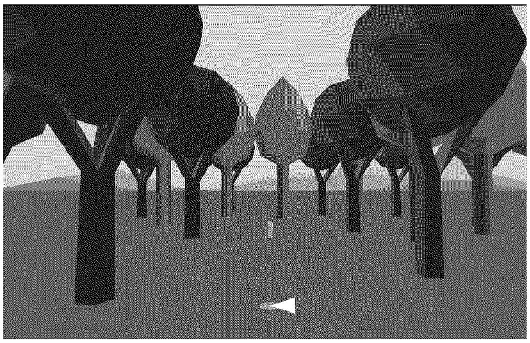

Figure 1: Starting point (circle) and end point (bar) of the presented route. The marker (triangle) has to be moved to the mid of the route. (note: ground texture has been deleted for printing reasons)

The presented routes differed with regard to their length — short (approximately 150 cm) or long (approximately 600 cm) — and with respect to the starting position of the marker (above the mid and below the mid). Each route hat to be bisected four times by each subject, twice in ascending and twice in descending order with respect to the initial position of the marker. The subjects stood 400 cm away from the route's starting point.
The participants in each experimental group were given different amounts of time to explore the virtual environment before their bisection task (30 seconds, 60 seconds and nor opportunity).

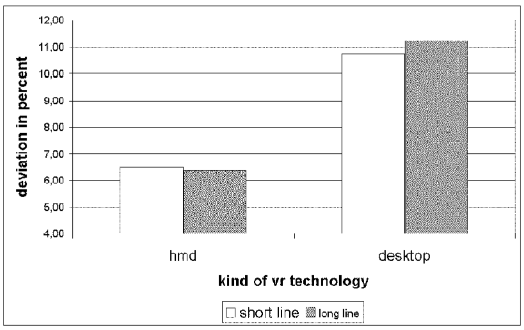

Figure 2: Bisection error (deviation from the real mid in percent) for the short and the long route under different VR-conditions (HMD, desktop)

The error of bisection was calculated as the absolute mean differences between the estimated mid and the real mid. Figure 2 shows that the bisection error is greater when the line is presented in desktop VR than when it is presented in HMD-VR. The difference is statistically significant ($F(1,12)=4,92$, $p<.05$). The factors "route length" and "experience with the virtual environment" did not affect the bisection error.
The results are showing that immersion improves depth perception and facilitates the judgement of distances in a virtual vista space.

3. Distance Cognition in Virtual Environments
There are two conflicting theories which try to predict the cognition of distances experienced in environmental spaces: the Feature-Accumulation-Theory (Sadalla & Magel, 1980) and the Route-Segmentation-Theory (Allen, 1988). According to the first theory, the cognitive distance of a route is positively correlated with the number of features experienced on the route, whereas the second theory proposes a positive correlation between estimated distance and the number of segmentations of the route.
Within the scope of those theories on distance cognition a series of experiments have been realised by Petra Jansen-Osmann in our institute. In the following section we report the main results of her doctoral thesis (Jansen-Osmann, 1999).

3.1 Number of route turns and estimated route length
The length of a route with more turns is estimated longer than a route with fewer turns. This result of an experiment carried out by Sadalla & Magel (1980) was replicated in a virtual maze. 20 subjects navigated successively through two mazes. The routes were of same length but differed in the number of turns (2 turns, 7 turns). Afterwards, they had to travel on a straight route until the distance covered seemed equal to the route travelled in the maze.
The covered distance was significantly de-pendent on the number of turns ($t(1,14)=3,56$, $p<.005$). The route with more turns was estimated longer (Figure 3).

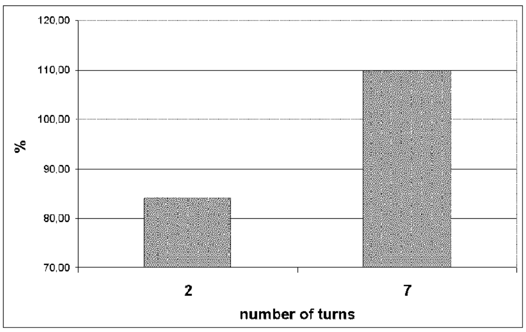

Figure 3: Cognitive distance (magnitude estimation) for routes with different numbers of turns

The result corresponds with both hypotheses on distance cognition because turns can on the one hand be regarded as features and on the other hand as borders of route segments, i.e. as segmentations.

3.2 Feature accumulation or route segmentation as determinants of distance cognition

In an experiment with 30 subjects distance estimations for segmented routes, routes enriched with features and empty routes were compared.

A street-scene was used in desktop-VR. On each side of the street 9 identical looking houses were presented. The number of houses and the number of crossways could not seen by the subjects from the starting point (Figure 4).

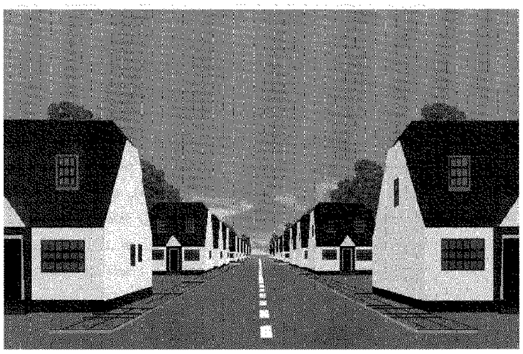

Figure 4: User's view at the starting point (note: crossways cannot be perceived at the starting point)

The spacing between the houses (Figure 5) as well as the location of crossways was varied. The subjects had to estimate six different distances between houses.

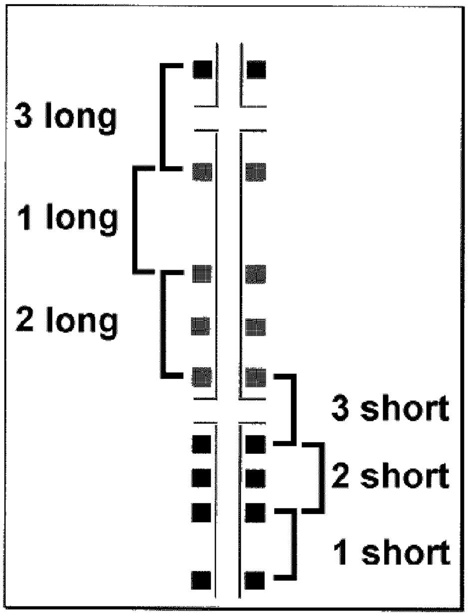

Figure 5: Empty sections (1), filled sections (2) and segmented sections (3) of different length in a survey map of the street scene used in the experiment

The whole route could be broken down in empty sections (1), sections filled with a house (2) or sections segmented through a crossways (3). Each kind of section could be short or long. Half of the group of subjects navigated through the virtual street using a joystick (active navigation), the other half experienced the street without joystick (passive navigation). Both groups experienced the environment three times successively.

Afterwards the subjects had to collocate the 9 houses on a vertical line on a sheet of paper with respect to their respective distances (Figure 6) and is consequently overestimated.

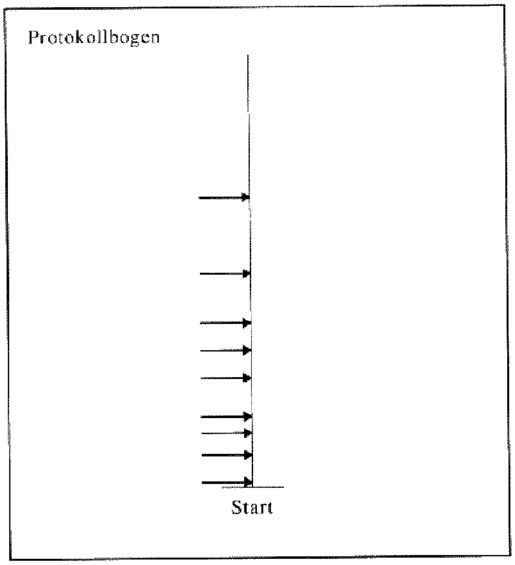

Figure 6: Protocol sheet: Collocation of the houses with respect to their distances

The results show that both the segmented and the filled sections were estimated equally longer than the empty sections of the route, and that this difference was more pronounced when the subjects had actively explored the virtual environment (Figure 7).

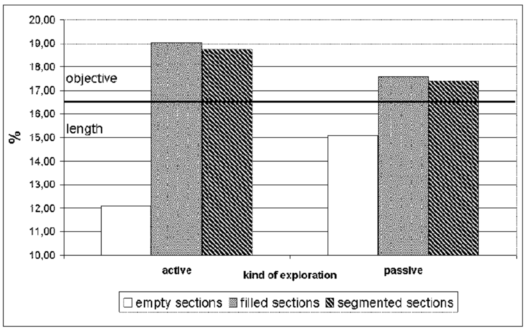

Figure 7: Cognitive distances (estimated length in relation to the total route length) of empty, filled and segmented route sections experienced actively or passively

Only the effect of the route design (empty, filled, segmented) on the distance estimations ($F(2,56)=12,16$, $p<.001$) was significant, showing that feature accumulation as well as route segmentation determine distance cognition in virtual environments.

3.3 Distance cognition based on the presentation of a survey map

Survey maps of the virtual streets used in the last experiment were presented to 15 subjects on a monitor for 1 minute after they had actively explored the virtual environment. Their distance judgements were clearly dependent only on route segmentation and not on feature accumulation (Figure 8).

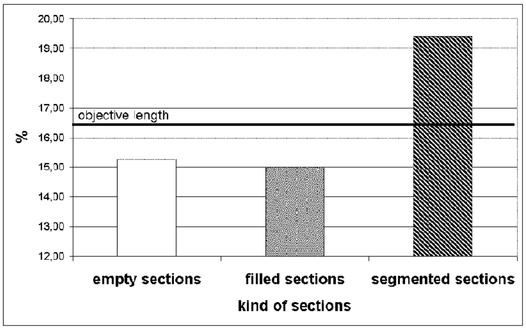

Figure 8: Cognitive distances (estimated length in relation to the total route length in percent) of empty, filled and segmented route sections experienced in a map

The route design significantly influences the distance estimation if the environment is presented on a map ($F(2,28)=8,73$, $p<.01$) but only the route segmentation — and not the feature accumulation — determines the perceptual organisation of the map and as a consequence the distance cognition (see Figure 9). When the street scene is presented as simultaneous structure the distance between two houses segregated by the crossways is perceptually strengthened.

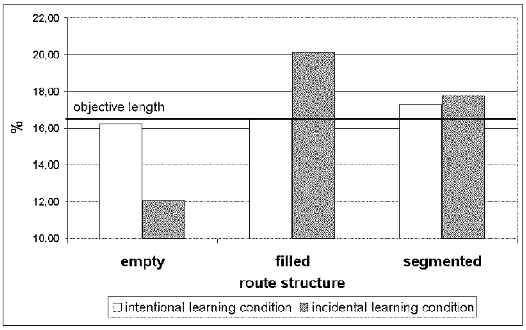

Figure 9: Cognitive distances (estimated length in relation to the total route length in percent) of empty, filled and segmented route sections in the case of incidental and intentional learning

3.4 Online- vs. inference-based distance judgement

The learner's goal when navigating through a virtual environment is a crucial encoding-factor in the processing of distances. In an experiment 30 subjects navigated through the same virtual environment used in the last two experiments. Half of them were instructed that afterwards they would have to estimate distances, whereas the other half was not explicitly instructed to focus on the distances.

There is a systematic interaction between the factors "route-design" and "kind of learning" ($F(2,56)=11,36$, $p<.01$) indicating that route-segmentation or feature-accumulation determine distance cognition only in case of incidental learning. If distances are learned intentionally, which means that the subjects encode distance directly, features and segmentations have no effect on the distance estimation: the distance estimation is based on the perceived distances (online judgement). In the case of incidental learning distances are not encoded directly, they are inferred afterwards using houses or crossways as heuristics (inference-based judgements).

4. Concluding Remarks

Accurate distance perception and distance cognition are necessary for applying VE in the field of training and are therefor a prerequisite for its validity as a training tool. There are differences in the accuracy of distance perception depending on whether the environments are presented in desktop- or HMD-VR: immersion improves depth perception and facilitates the judgement of distances in a virtual vista space. Obviously the perceiver's sensumotoric interaction with the virtual environment provided by the tracking system enhances his spatial sensitivity.

Distance cognition in a virtual environmental space can be based on online-judgements (perception based) or on inferential judgements (memory based) depending on the subject's goal when navigating through the environment. The learner's goal is a crucial encoding-factor in the processing of distance-information. It determines the kind of spatial knowledge transferable from the virtual to the natural environment.

When VE are applied in the training of real world skills based on accurate distance perception and cognition, the designer should be familiar with psychological factors which determine the learner's spatial encoding and judgement of distances (e.g. the role of feature-accumulation). It was shown that without an explicit goal to learn distances the learner stores general information (features) when navigating through the environment, and later on judges the distance of a route by using the frequency of features experienced on the route as a heuristic.

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